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# Analysis of Physiological and Biochemical Parameters in the Radish (*Raphanus sativus* L.) Obtained in Different Cultivation Systems

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## Abstract

This paper presents the results obtained from the analysis of physiological and biochemical parameters in the radish, species *Raphanus sativus* L., variety Rond Ecarlate, which was grown in three different systems (in the field, in the solarium and in the climate chamber). Several parameters necessary for the evaluation of biomass, physiological processes and nutritional values were determined. Regarding the biometric parameters, it was noticed that in the field cultivation the plants formed 11-12 leaves, in the solarium average 12-13 leaves, and in the climatic chamber the analyzed plants formed 7-9 leaves, on an average. The total biomass of the plant was recorded with the following average values: in the field 70.05 grams, in the solarium 92.3 grams and in the climate chamber 32.9 grams. Regarding the circumference of the tuberous hypocotyl axis, the values are higher in plants grown in solarium (16.9 cm), with the smallest dimensions being recorded in plants grown in the climate chamber (7.2 cm). The highest average pulp firmness value was observed in plants grown in the solarium (0.27 kg force), and the lowest values were seen in plants grown in the climate chamber (0.14 kg force). Regarding the amount of water lost through perspiration by the leaves of radish plants, the highest average values were recorded at plants grown in the solarium, and the lowest at plants grown in the climatic chamber. The average soluble dry matter content was higher (over 4%) in plants grown in the climate chamber compared to other harvesting systems. The analysis of the average carbohydrate content shows that the total soluble carbohydrates were present only in the hypocotyl axis and glucose was found both in the hypocotyl axis of the studied plants and in the leaves. Vitamin C was present in variable amounts, both in the hypocotyl axis and in the leaves. The average amino acid content (expressed in amino nitrogen) was between 0.003% and 0.006%. The anthocyanin was present with highest values (54.5 mg) in field-grown plants, and catalase activity was present both in the hypocotyl axis and in the leaves and roots. Air humidity and temperature had a high influence on the development of plant biomass, on the content of dry matter and on the loss of water through transpiration. The biometric, physiological and biochemical parameters varied depending on the cultivation system.

## Keywords

*Raphanus*; Physiological parameters; Biochemical parameters; Cultivation system

## Introduction

Radish (*Raphanus sativus* L.) is one of the most popular root vegetable crops, which is cultivated for its enlarged edible roots. It is a quick growing and short duration vegetable crop suitable for growing both in temperate and tropical climate (Ahmad *et al*., 2020). Radishes are grown especially for tuberous roots that can be eaten both raw and in different salads (Ciofu *et al*., 2004). The roots have a sweet, spicy taste, varying depending on the conditions in which they were grown (Apahidean and Apahidean, 2001). The pungent taste of radishes is given by allyl sulfide (Ciofu *et al*., 2004). Moon radish contains 4-7% dry matter, 3.5-5% carbohydrates, 0.5-1.1% proteins, vitamins B1, C (20-35 mg/100 g), and mineral salts: calcium, phosphorus, magnesium and volatile substances (Apahidean and Apahidean, 2001). Due to their high content of volatile substances, radishes have a diuretic, bactericidal and deworming action (Schippers, 2004). They are also a good detoxifier and immune booster (Voican and Lacatusu, 2007). Radish can be eaten with the leaves, which have much stronger vitaminizing and re-mineralizing properties than the roots (Burzo *et al*., 2000). Moon radish leaves contain vitamins A, B1, B2 and C, and they have purifying and antitoxic properties (Burzo *et al*., 2000). Anthocyanins, the most abundant of phenolic compounds contained in most vegetables and fruits, including radishes, grapes, berries and red cabbage, are highly regarded because of their attractive colors and, especially, their numerous health benefits (Araceli *et al*., 2009). Many investigations have indicated that anthocyanins can prevent or delay the onset of chronic age-related diseases owing to their antioxidant activities (Feng *et al*., 2016). Furthermore, anthocyanins have been reported to restrain the proliferation of cancer cells due to their anti-proliferative capacities (Sousa *et al*., 2016). Consumed in the form of salad or juice, the leaves can have benefits in treating biliary and liver diseases, in combating spring asthenia and they are ideal in weight loss diets due to their very low caloric content (Gherghi *et al*., 2001).

In this study, we started from the hypothesis that, in protected spaces and with controlled environmental factors, plants, in general, and radishes, in particular, grow and develop to the optimal potential of the species. The objectives pursued in the study consist of comparative analysis of some biochemical and physiological parameters of radishes obtained in three cultivation systems, recommendations for producers related to the most favorable cultivation system.

## Material and Methods

Radish seeds from a producer authorized by the Ministry of Agriculture, within the validity period, were used. Systematic classification of biological material: Reign - *Plant*, Sub - Reign - *Tracheobiont*, Branch - *Magnoliophyta*, Class - *Magnoliopsida*, Subclass - *Dileniidae*, Order - *Capparales*, Family - *Brassicaceae*, Species - *Raphanus sativus*, Variety - Rond Ecarlate. The Rond Ecarlate variety has a crispy tuberous hypocotyl axis tissue, intense red color, early blossoming of fine leaves (Ceausescu *et al*., 1984). Harvesting is done in stages, 4-6 weeks after sowing (Apahidean and Apahidean, 2001). In protected environments, it can be cultivated almost all year round; and in the open field, it is cultivated in spring starting with March and in autumn starting with the end of August (Voican, 2012). It is a variety that allows a staggered harvest by sowing in stages, at intervals of 2-3 weeks. Sowing is preferably carried out in rich, moist

soil by spreading or in rows on the surface, after which it is lightly covered with soil by raking and watered frequently (Voican and Lacatusu, 2007). Germination occurs in 3-4 days at temperatures of $12^0$ C.

In order to observe the influence of environmental factors on the physiological and biochemical parameters of radishes, it was decided to cultivate them in three different systems, namely: field, solar and climate chamber. All three cultivation systems were established on 20.03.2022. The seeds were planted by direct sowing. The radishes in the field emerged on 25.03.2022. Those in the solarium on March 23, 2022 and those in the climate chamber on March 24, 2022. During the vegetation period (42 days), the following indexes were monitored: temperature, atmospheric humidity and the number of leaves developed. A series of parameters necessary for the evaluation of biomass, physiological processes and nutritional value were determined: air temperature, atmospheric humidity, evolution of leaves number, total plant biomass, tuberous hypocotyl axis biomass, leaf system biomass, root biomass, tuberous hypocotyl axis circumference, tuberous hypocotyl axis firmness, dry matter, leaf moisture and perspiration, soluble dry matter, soluble total carbohydrates, glucose, vitamin C content, anthocyanin content from the hypocotyl axis epidermis, catalase activity, amino acids.

The alcohol thermometer was used to measure the air temperature, the hygrometer was used to determine the relative humidity of the air and a precision electronic balance was used for the gravimetric determinations. The firmness determination of the tuberous hypocotyl axis was performed using the Extech FHT 200 penetrometer, and the amount of dry matter was determined by drying the biological material using the Binder Drying System. The soluble dry matter was determined by the refractometer method (Bratu, 2005), the soluble carbohydrates by the polarimetry method (polarimeter P1000), and the anthocyanin pigments by the spectrophotometric method (spectrophotometer UV-VIS). The amount of glucose, vitamin C, amino acids and the activity of catalase were determined by titrimetric methods. Statistical data processing was done by using Microsoft Office Excel (average, homogeneity, standard deviation, CV–Pearson correlation). Data were first evaluated for their normality and homogeneity. Linear Pearson correlation was performed to identify the degree of relationship between the independent variables.

## Results and Discussion

In this study, some physiological and biochemical parameters were investigated, revealing variations in different cultivations systems. The obtained results are presented in the tables 1 – 4.

Table 1 shows that the maximum values for the analyzed biometric indicators were recorded for plants grown in the solarium, and the minimum for plants grown in the climate chamber. The total biomass has high values for plants grown in solar (92.3%) and for those grown in the field (70.05%). By comparison with these, the plants grown in the climate room show a significantly lower total biomass. Regarding the total biomass, the biggest part was occupied by the tuberous hypocotyl axis, followed by the foliar system. The biomass of the root system has the lowest values, being between 0.4 and 0.77 grams in all growth systems. From the total biomass of plants grown in the

field, 54.2% was occupied by the biomass of the tuberous hypocotyl axis, 45% by the biomass of the leaf system and only 0.8% by the biomass of the root system. From the total biomass of the plants grown in the solar, 62.8% was occupied by the biomass of the tuberous hypocotyl axis, 36.4% by the biomass of the leaf system and 0.8% by the biomass of the roots. From the total biomass of the plants cultivated in the climatic chamber, 23.7% was occupied by the biomass of the tuberous hypocotyl axis, the largest part of the biomass was represented by the leaf system, 75.1%, and the biomass of the roots occupied 1.27%.

Table 1: The biomass of different organs of the plant and some biometric indicators (average values)

| *Sl. No.* | *Cultivation system* | *Number of leaves* | *Total biomass (grams)* | *Tuberous hypocotyl axis biomass (g)* | *Foliar system biomass (g)* | *Root biomass (g)* | *Circumference of the tuberous hypocotyl axis (cm)* |
|---|---|---|---|---|---|---|---|
| 1. | Field | 11-12 | 70.05 | 37.9 | 32.1 | 0.57 | 13.1 |
| | Std. deviation | | 5.311858 | 3.832319 | 5.017553 | 0.147902 | 1.358921 |
| | CV | | 7.6% | 10,1% | 15.6% | 25.7% | 10.5% |
| 2. | Solarium | 12–13 | 92.3 | 58.0 | 33.5 | 0.77 | 16.9 |
| | Std. deviation | | 12.90023 | 9.740979 | 5.14166 | 0.238485 | 0.866025 |
| | CV | | 14.0% | 16.8% | 15.3% | 30.8% | 5.1% |
| 3. | Climate chamber | 7-9 | 32.9 | 7.8 | 24.7 | 0.4 | 7.2 |
| | Std. deviation | | 2.211334 | 0.619139 | 1.519868 | 0.070711 | 1.81659 |
| | CV | | 6.7% | 7.9% | 6.1% | 17.7% | 25.2% |

Depending on the cultivation system, the average number of leaves was between 7 and 13. The maximum number of leaves per plant is obtained from plants grown in the solar system. The plants grown in the climate chamber formed the minimum number of leaves. The circumference of the tuberous hypocotyl axis presented values between 7.2 and 16.9 cm. High values of this character were obtained for radishes grown in the solarium, followed by those grown in the field. Although in the climate chamber the environmental parameters are controlled and set according to the biological requirements of the plants, the biometric parameters in table 1 presented the lowest values. The coefficient of variation (Pearson) showed values lower than 30% in all three cultivation systems. This shows a moderate degree of homogeneity of these parameters and a representative average. In the plants grown in the climate room, a coefficient of variation below 10% is observed for three parameters (total biomass, biomass of the tuberous hypocotyl axis and biomass of the leaf system). This shows a high degree of homogeneity and the average is representative for the analyzed parameters. In the case of the biomass of roots from radishes grown in the sun, the coefficient of variation exceeds the value of 30% (respectively 30.8%), which shows a moderate heterogeneity of this character.

In 2015, Caser (2015) showed that low temperature (4°C) influenced the development of radishes by increasing biomass accumulation in storage organs (roots) and accelerating plant growth (relative growth rate, net assimilation rate). Increased shoot root ratio and specific leaf area showed that under ordinary temperature conditions (18/14ºC) radish grew more leaves but accumulated less assimilate products in roots. Turnip can grow more intensively than the leaves. The change in the ratio of roots-to-leaves growth rate occurs predominantly during the changing sunlight intensity and nutrition intensity (Poorter *et al*., 2012; Suqiura and Tateno, 2011). The change of leaves-to-roots weight ratio occurs probably only to a certain extent, and it is determined genetically, via optimization of the growth rate of the whole plants (Osone and Tateno, 2003). Similarly, the roots of sugar beet, fodder beet and turnip can grow more intensively than the leaves. Formation of leaves is supported heavily by nutrition, however, the light sufficiency has the opposite effect (Poorter *et al*., 2012).

Table 2: Physiological determinations (average values)

| *Sl. No.* | *Cultivation system* | *Dry matter (%)* | | *Humidity content (%)* | | *Firmness of the tuberous hypocotyl axis (kg force)* | *Amount of water lost through perspiration (g / hour)* | |
|---|---|---|---|---|---|---|---|---|
| | | *Tuberous hypocotyl axis* | *Leaves* | *Tuberous hypocotyl axis* | *Leaves* | | *Young leaf* | *Mature leaf* |
| 1. | Field | 6.66 | 8.51 | 93.34 | 91.49 | 0.21 | 0.896 | 0.452 |
| | Std. deviation | 0.796508 | 0.541071 | 0.796508 | 0.541071 | 0.02582 | 0.025987 | 0.047937 |
| | CV | 11.96% | 6.4% | 0.9% | 0.6% | 12.3% | 2.9% | 10.6% |
| 2. | Solarium | 3.57 | 5.66 | 96.43 | 94.34 | 0.27 | 0.824 | 0.668 |
| | Std. deviation | 0.544304 | 0.640364 | 0.544304 | 0.640364 | 0.084853 | 0.056291 | 0.054467 |
| | CV | 15.2% | 11.3% | 0.6% | 0.7% | 31.4% | 6.8% | 8.2% |
| 3. | Climate chamber | 7.40 | 8.50 | 92.60 | 91.50 | 0.14 | 0.146 | 0.798 |
| | Std. deviation | 0.88698 | 1.064863 | 0.88698 | 1.064863 | 0.040825 | 0.037479 | 0.072677 |
| | CV | 11.97% | 12.5% | 0.96 | 1.2% | 29.2% | 25.7% | 9.1% |

Table 2 presents the physiological parameters on different plant organs. High values are recorded for plants grown in solarium conditions at most parameters. Regarding the amount of dry matter, the maximum values were recorded for plants grown in the field and in the climate chamber. The values recorded regarding the dry matter were framed between 3.75% - 7.40% for the tuberous hypocotyl axis and between 5.66% - 8.51% for the leaves. CV had values between 11.96% and 15.2% at the tuberous hypocotyl axis, which indicates a high homogeneity of this character in all three cultivation systems studied. In the case of dry matter present in leaves, the CV values are even lower (6.4% - 12.5%), showing a high degree of homogeneity. The water content had a peak value of 96.43% and 91.49% at the lowest. The water content is higher in the tuberous hypocotyl axis compared to the leaves, but the values of this parameter are quite close to each other in both plant organs. Here we can see a CV with very low values both in the tuberous hypocotyl axis and in the leaves. This means that these characters are very homogeneous and their average is representative.

The firmness of the tuberous hypocotyl axis decreased while the temperature of the environment in which the plants were grown increased. The lowest value of this indicator was observed at radishes grown in the climate chamber. The maximum values of the analyzed radish firmness were obtained from the plants grown in the solarium. The coefficient of variation (Pearson) in this case has two values that exceed 20% (29.2% and 31.4%) that indicate a moderate heterogeneity of the respective character.

The loss of water through perspiration is observed to have occurred in the largest proportion in the young leaves of the plants grown in the field and in the solarium rather than the mature ones. In young leaves grown in the field and in the solarium, the values of water loss through transpiration are the highest (0.896 and 0.824 g/hour), indicating a greater intensity of this process compared to mature leaves and, at the same time, correlated with environmental factors. However, the young leaves in the climate chamber did not have the same rate of water loss through transpiration; in this case the lowest value of this parameter was recorded (0.146 g/hour). Mature leaves show relatively similar values of water loss in all cultivation systems. The CV of this parameter shows a very high degree of homogeneity of the analyzed series, with values below 10% for both young and mature leaves, with two exceptions: 10.6% for mature leaves of plants grown in the field and 25.7% for young leaves of plants grown in the climate chamber.

The overall range of dry matter content variability in root crops was quite high. The dry matter content in the root crops ranged from 3.72% to 8.56% in the small radish (CV = 21.4%), and from 5.28% to 13.64% in the radish (CV = 24.1%). At the same time, the accessions of the small radish sub-species *sinensis* accumulated more dry matter than the accessions of sub-species *sativus*. In the radish, on the contrary, the accessions of sub-species *sativus* were characterized by high dry matter content (Kurina *et al*., 2021). The majority of radish accessions accumulated dry matter in the range of 6.5–9.5% (Kurina *et al*., 2021).

Table 3 shows that the soluble dry matter showed different average values in all cultivation systems. High values of soluble dry matter were noticed in the plant`s leaves. The highest value was recorded in the field cultivated plants (6%). The soluble dry matter values of the tuberous hypocotyl axis were between 2.75% and 4.7%. In the leaves, this parameter fell between 4.15% and 6%, and 2.8% and 4.05% in the stalk. Regarding the cultivation system, the soluble dry substance showed higher values in the samples taken from the plants grown in the climate chamber. The coefficient of variation (Pearson) of this parameter was below 20% in all cases, indicating a high degree of homogeneity of the samples compared to the average values. Total soluble carbohydrates were present only in the tuberous hypocotyl axis, and glucose was present in both organs of the analyzed plants. Plants grown in the climate chamber had the highest values of the total soluble carbohydrates followed by plants cultivated in the solarium. This parameter was not present in the leaves. Glucose was identified in both analyzed plant organs, with similar percentage contents of it (0.60% - 0.90%). The coefficient of variation of the carbohydrate content shows a high closeness to the average value and a homogeneity of the data.

About 80% of the dry matter consists of carbohydrates such as sugars, starch, fiber, pectin, and other substances. The predominant part of the dry matter of small radish and radish root crops is represented by mono- and disaccharides, and, therefore, this indicator

is of great importance for the comparative evaluation of accessions. Depending on the variety, the sugar content in the dry matter can reach 25%–55% (Shebalina and Sazonova, 1985).

Table 3: Average soluble dry matter content and average carbohydrate content

| *Sl. No.* | *Cultivation system* | *Soluble dry matter (%)* | | | *Average carbohydrate content (%)* | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | *Total soluble carbohydrates (%)* | | *Glucose (%)* | |
| | | *Tuberous hypocotyl axis* | *Leaves* | *Stalk* | *Tuberous hypocotyl axis* | *Leaves* | *Tuberous hypocotyl axis* | *Leaves* |
| 1. | Field | 3.75 | 6.0 | 2.8 | 0.65 | - | 0.60 | 0.81 |
| | Std. deviation | 0.247386 | 0.643843 | 0.257811 | 0.018257 | - | 0.08165 | 0.080829 |
| | CV | 6.6% | 10.7% | 9,2% | 2.8% | - | 13.6% | 10% |
| 2. | Solarium | 2.75 | 4.9 | 4.05 | 0.81 | - | 0.69 | 0.60 |
| | Std. deviation | 0.402078 | 0.382884 | 0.796702 | 0.074386 | - | 0.055976 | 0.08165 |
| | CV | 14.6% | 7.8% | 19.7% | 9.2% | - | 8.1% | 13.6% |
| 3. | Climate chamber | 4.7 | 4.15 | 3.25 | 0.90 | - | 0.86 | 0.90 |
| | Std. deviation | 0.389273 | 0.222561 | 0.546199 | 0.066332 | - | 0.058878 | 0.070711 |
| | CV | 8.2% | 5.4% | 16.8% | 7.3% | - | 6.8% | 7.9% |

In this study, the sugar content in the dry matter was 35%–77% in small radish, and 13%–47% in radish. The high variability of this biochemical trait is associated with both genetic characteristics and climatic conditions of cultivation. The total sugar content averaged 2.14% (0.16–5.45%) in small radish and 2.34% (1.03–4.31%) in radish, of which the monosaccharide content was 1.9% and 2.0%, respectively (Kurina *et al*., 2021). Low temperature had the strongest effect on the carbohydrate accumulation in roots and shoots (Caser, 2015). At the maturity stage, there were no differences in carbohydrate contents. Moreover, the dry weight of roots increased due to carbohydrate allocation from shoots to roots. Under low temperature and short-day photoperiod, relative growth and net assimilation rates of radishes were higher during all experiment (Sirtautas *et al*., 2011).

A higher content of proteins may be associated with an increase in the carbohydrate content in leaves. In turn, a greater amount of sugars generally accelerates nitrogen inclusions through the nitrate assimilation pathway. This increased growth can be also ascribed to sugars that serve as an energy source and stimulate nitrogen uptake. Carbohydrates provide the skeleton for the incorporation of reduced nitrate (ammonia) in amino acids and increased protein biosynthesis. The enhancement of sugar biosynthesis in plants is also linked to the higher content of chlorophyll, net photosynthesis, and quantum efficiency of photosystem II (Bulgari *et al*., 2019).

The vitamin C and the amino acid contents are higher in the tuberous hypocotyl axis (Table 4), and the catalase activity is higher in the leaves of the plants (more than in any other organs) in all three cultivation systems. Ascorbic acid synthesis is strongly influenced by light intensity. The organs of radish plants grown in direct light in the field are richer in ascorbic acid than those grown in the shade. High values of vitamin C

content are remarked in plants grown in the field and in the climate chamber (34 mg/100 g FS and 32 mg/100 g FS). Larger amounts of vitamin C are contained in the leaves of radishes grown in the field and in the climate chamber. The amount of vitamin C accumulated in the leaves of plants grown in the solarium is the lowest. The content of vitamin C in the plants grown in the climate chamber is approximately equal both in the tuberous hypocotyl axis and in the leaves. In the field and in the solarium, there are differences regarding the amount of vitamin C present in the leaves and in the tuberous hypocotyl axis. In this case, CV has values between 2.4% - 22.6%.

Table 4: Average content of vitamin C, amino acids, anthocyanins and catalase activity

| *Sl. No.* | *Cultivation system* | *Vitamin C content (mg / 100 g FS)* | | *Amino acid content (% N amine)* | | *Anthocyanin content in the epidermis of the hypocotyl axis (mg/100 g FS)* | *Catalase activity (EU)* | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Tuberous hypocotyl axis* | *Leaves* | *Tuberous hypocotyl axis* | *Leaves* | | *Tuberous hypocotyl axis* | *Leaves* | *Root* |
| 1. | Field | 16 | 34 | 0.005 | 0.004 | 54.5 | 0.14 | 0.27 | 0.08 |
| | Std. deviation | 1.414214 | 4.320494 | 0.000816 | 0.001414 | 3.291403 | 0.008165 | 0.02708 | 0.014142 |
| | CV | 8.8% | 12.7% | 16.3% | 35.4% | 6% | 5.8% | 10% | 17.7% |
| 2. | Solarium | 24 | 7 | 0.005 | 0.003 | 36.2 | 0.06 | 0.38 | 0.12 |
| | Std. deviation | 0,816497 | 1.581139 | 0.000816 | 0.000816 | 0.993311 | 0.008165 | 0.021602 | 0.014142 |
| | CV | 3.4% | 22.6% | 16.3% | 27.2% | 2.7% | 13.6% | 5.7% | 11.8% |
| 3. | Climate chamber | 34 | 32 | 0.005 | 0.006 | 50 | 0.07 | 0.15 | 0.11 |
| | Std. deviation | 0.816497 | 2.12132 | 0.000816 | 0.000816 | 4.242641 | 0.008165 | 0.033665 | 0.014142 |
| | CV | 2.4% | 6.6% | 16.3% | 13.6% | 8.5% | 11.7% | 22.4% | 12.9% |

A higher content of vitamin C in older than younger leaves of lettuce and broccoli was shown by Omar *et al.* (2003). Similarly, Cheptoo *et al.* (2019) claim a higher content of vitamin C in older than younger leaves of amaranth plants. On the contrary, the decrease in the content of vitamin C in dill leaves in successive days of the growing season was a measure by Lisiewska *et al.* (2006). The radish roots from the last harvest (9 May) had a higher content of vitamin C than roots from the previous harvest (3 May). On the contrary, in the leaves the content of vitamin C declined between 3 May and 9 May. The older leaves contained less vitamin C than the younger ones (Kovacik *et al.*, 2021). Results revealed a compared vitamin C content in the samples with another researchers. The accumulation of vitamin C is known to be influenced by growing conditions (Bimenindavy and Tymofeeva, 2020). This suggests that the observed vitamin C content in my samples may have been impacted by environmental conditions.

Ascorbic acid (vitamin C) is one of the important biologically active substances in *R. sativus* crops. In the roots of small radish and radish, it is present in its free form, bioavailable to humans. The average content of ascorbic acid in the roots of small radish is 30.47 mg/100 g (19.04–57.72 mg/100 g), and in radish 42.02 mg/100 g (11.80–73.32 mg/100 g) (Kurina *et al.*, 2021). In all cases, the amino acids content present in the tuberous hypocotyl axis remained the same, with a slight change in the leaves. However,

in the case of amino acids present in the leaves, the CV has higher values (13.6% - 35.4%) which suggests a heterogeneity of this character. Catalase activity is more intense in the leaves than in the tuberous hypocotyl axis and in the roots of radishes.

The increased activity of catalase in the leaves can be explained according to the activity of this enzyme with the degree of hydration of the soil in which the plants are grown. Also, due to the lower temperatures recorded in the field, a higher catalase activity was observed. The anthocyanin content found in the tuberous hypocotyl axis epidermis was higher in plants grown in the field (54.5 mg/100 g FS) and the climate chamber (50 mg/100 g FS). According to CV (2.7% - 22.4%), anthocyanin content and catalase activity show a high degree of homogeneity. Figure 1 and 2 show the dynamic values of temperature and air humidity recorded during the growing season of radishes. The vegetation period was 42 days.

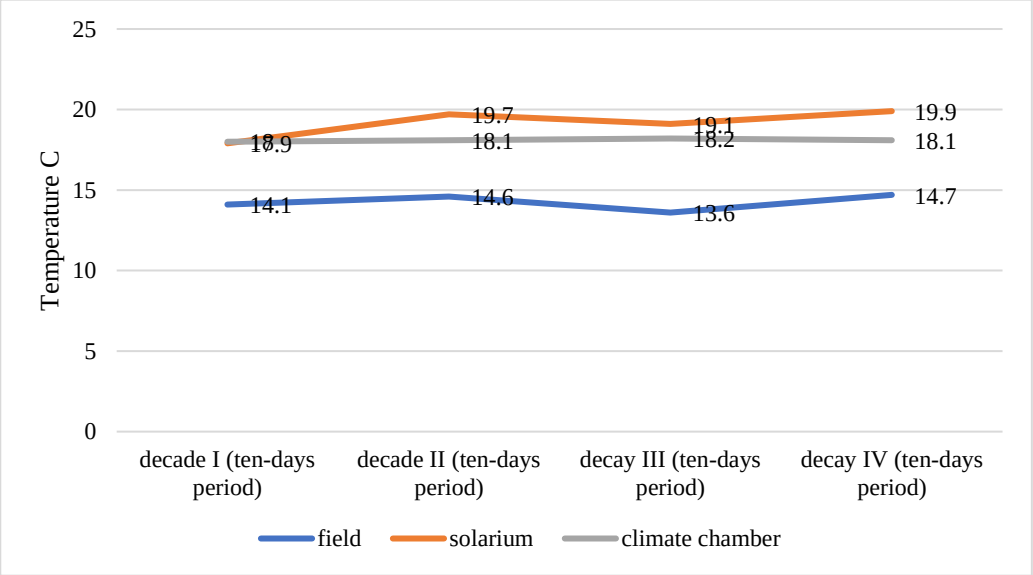



Figure 1: Temperature evolution during the vegetation period

In the field, the temperature had relatively constant values during the vegetation period, varying very little, on average, per decade (between $13.6^0$C - $14.7^0$C). In the solarium, the temperature was around $19^0$C, with a minimum of $17.9^0$C and a maximum of $19.9^0$C. The temperature in the climate chamber was set around $18^0$C.

Air humidity had values between 45 and 53% in the field, between 61.5 and 70% in the solarium and between 70 and 75% in the climate chamber. During the vegetation period, the relative air humidity values remained relatively constant for each growing system.

Figure 3 shows the correlation between ambient temperature and the development biomass in radishes grown in the three cropping systems. The coefficient of correlation show that there is a strong correlation between the parameters. Under the influence of the temperatures in the solarium and in the field, the total biomass showed a more pronounced increase compared to the total biomass of the plants grown in the climatic chamber. The coefficient of determination in this case ($R^2$=0.5327) shows that in

approximately 53% of cases, the total biomass is influenced by the variation of the ambient temperature.

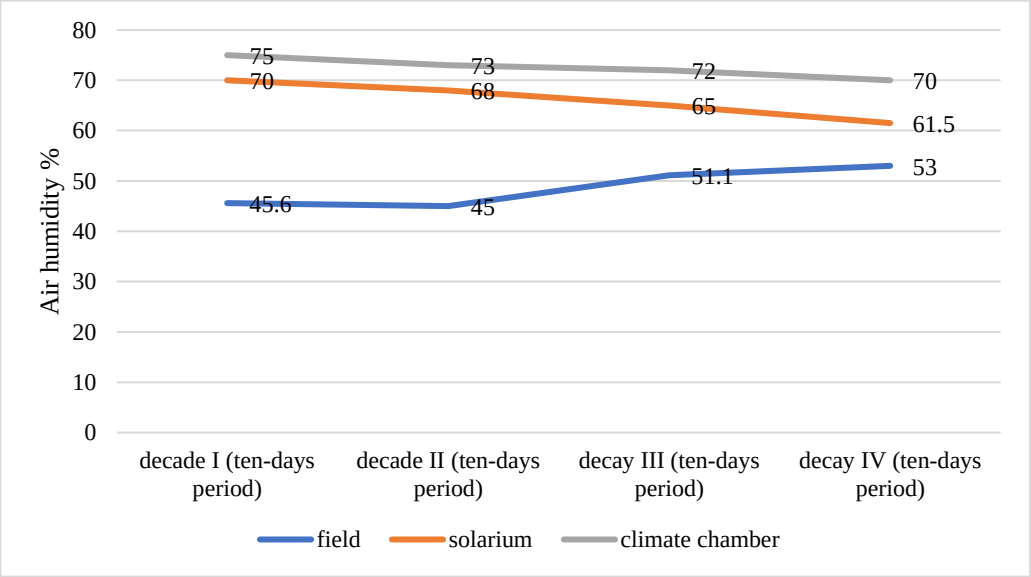
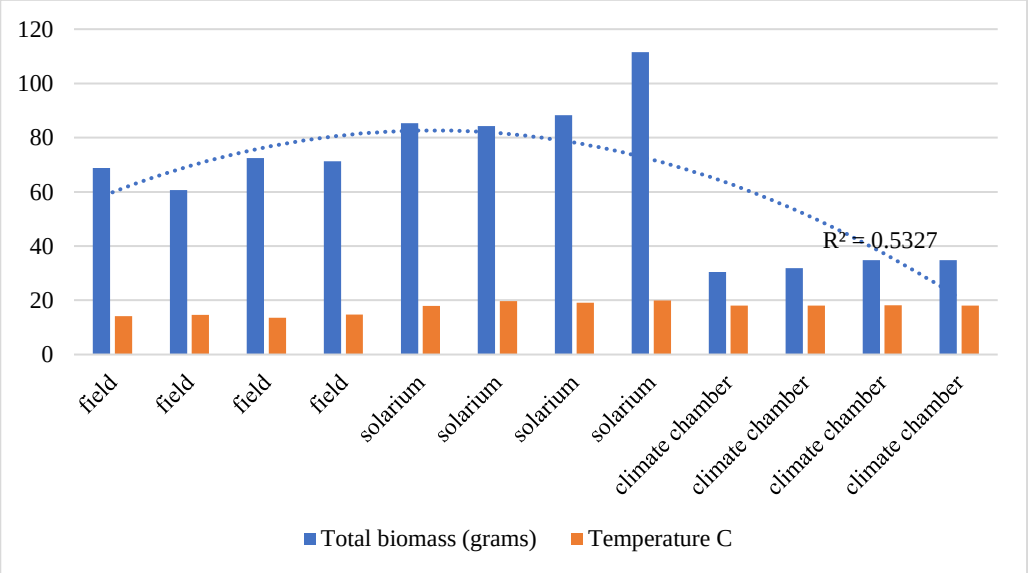
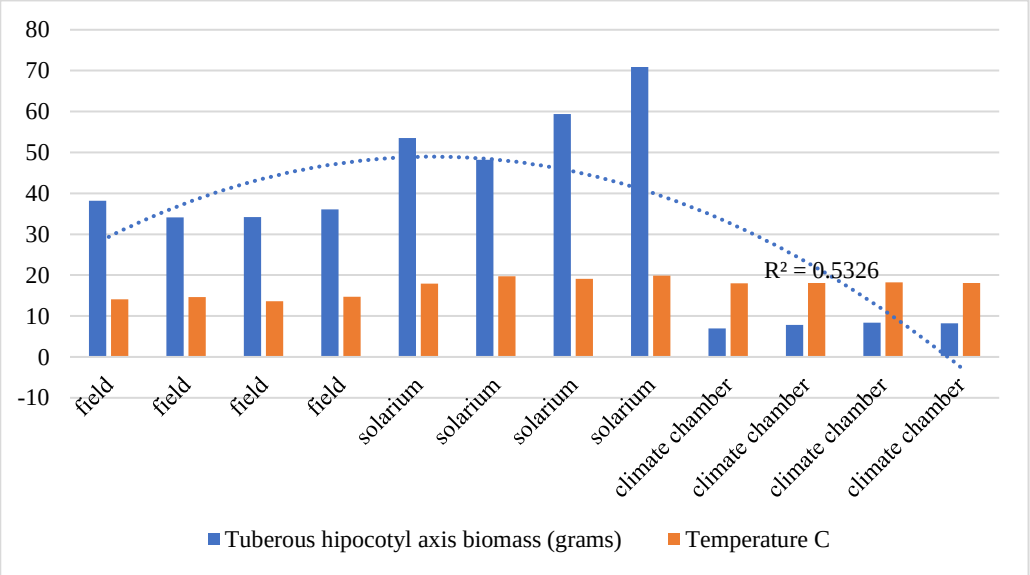



Figure 2: Air humidity evolution during the vegetation period




The correlation coefficient: 0.181487
The significance of the correlation coefficient: 0.583604
t: -1.81246
Figure 3: Correlations between temperature and total plant biomass

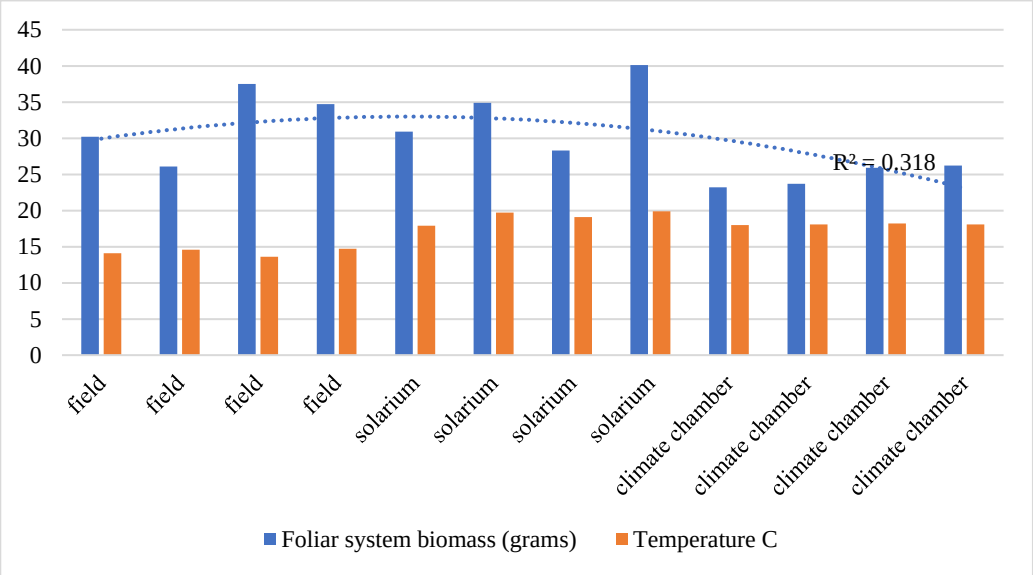



The correlation coefficient: 0.172255
The significance of the correlation coefficient: 0.552985
t: -1.81246
Figure 4: Correlations between temperature and tuberous hypocotyl axis biomass

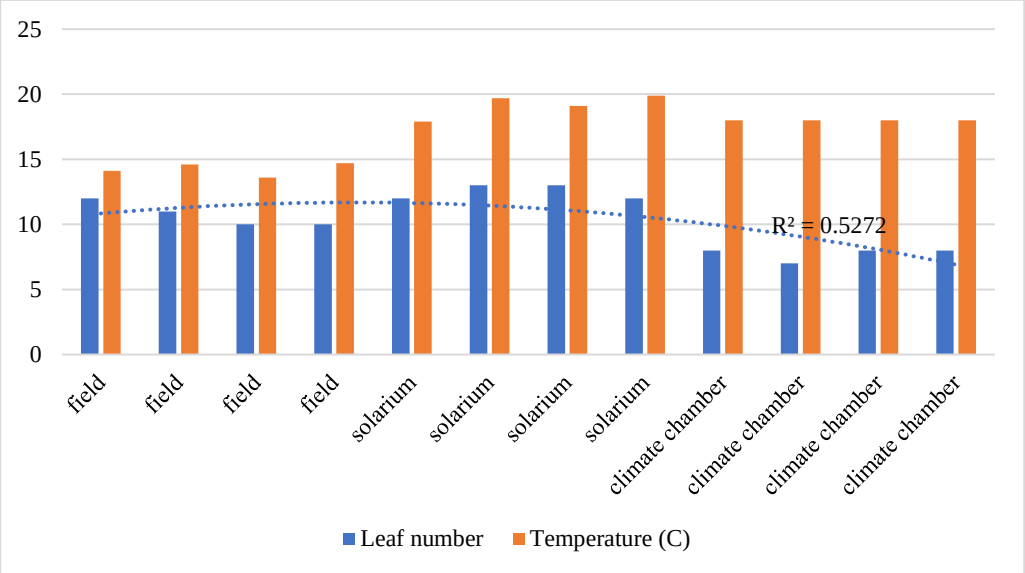
The high temperature value in the solarium stimulated the accumulation of the biomass of the tuberous hypocotyl axis, showing higher values compared to the other two cultivation systems. Thus, temperatures between 17.9$^0$C and 19.9$^0$C in the solarium contributed to the increase in the biomass of the tuberous hypocotyl axis, reaching the maximum values (70.9 g). In the other two growing systems, the value of the biomass of the tuberous hypocotyl axis was similar to the plants grown in the solarium. However, temperature, as an environmental factor, had a reduced influence upon the accumulation of biomass in the tuberous hypocotyl axis, in plants cultivated in the climate chamber. In the climate chamber, the biomass of the tuberous hypocotyl axis showed the lowest values. In the field, the values of this parameter are close to those of the plants cultivated in the solarium.

Apart from temperature, the biomass of the foliar system of the studied species, can also be influenced by other environmental factors (soil moisture and air humidity) and technological factors. The value of the coefficient of determination shows that in only 31% of cases the variation of the biomass of the foliar system is determined by the temperature variation. High values of the biomass of the foliar system are observed in the case of plants grown in the field and in the solarium. However, in the case of this parameter, relative close values to the other cultivation systems were observed in the climate chamber.

Low temperature (4°C) influenced the development of radishes by increasing biomass accumulation in storage organs (roots) and accelerating plant growth (relative growth rate, net assimilation rate). Increased shoot: root ratio and specific leaf area showed that under ordinary temperature conditions (18/14ºC) radish grew more leaves but accumulated less assimilate products in roots (Caser, 2015).




The correlation coefficient: 0.170171
The significance of the correlation coefficient: 0.546093
t: -1.81246
Figure 5: Correlations between temperature and foliar system biomass

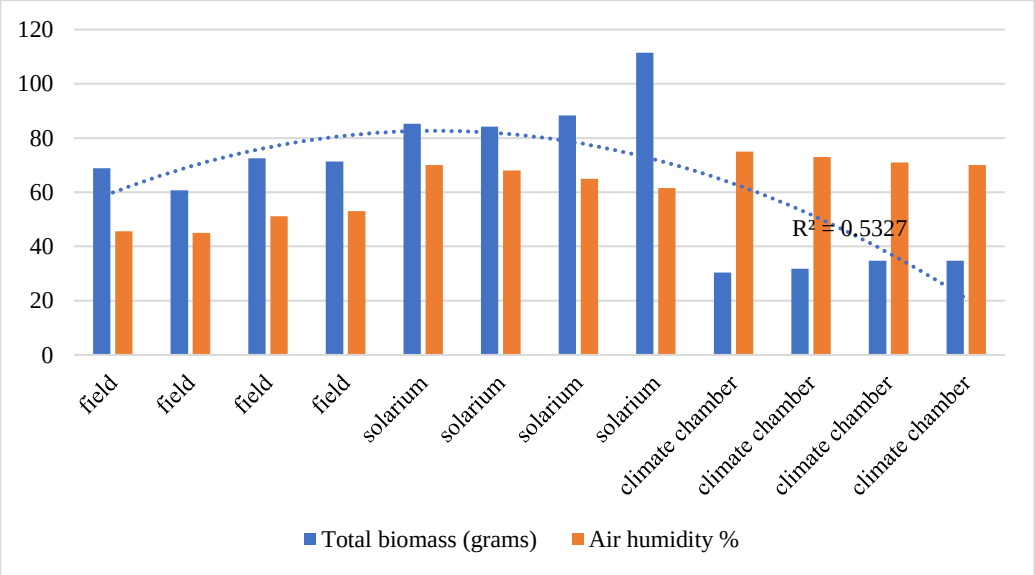



The correlation coefficient: 0.06045
The significance of the correlation coefficient: 0.191509
t: -1,81246
Figure 6: Correlations between temperature and the number of leaves

According to figure 6, the temperature influenced the total number of leaves of the plants, the correlation coefficient obtained in this case proving this. Besides the genetic characteristic of the species, the number of leaves is influenced by the temperature values

during the vegetation period. In the field and in the solarium, the plants showed a higher number of leaves compared to the plants grown in the climate chamber. The value of the coefficient of determination shows that in 52% of cases the variation of the number of leaves is determined by the temperature variation.

Caser (2015) demonstrated that radish grown in 20°C cabinet substantially exceeded that of 12°C in plant leaves dry weight (13.13%), leaf number (7.6%) and mid-blade length (13.6%). On the other hand, 12°C showed superiority over 20°C in plant leaves fresh weight and leaves thickness by 12.1% and 33.6%, respectively. Radish grown in 20°C cabinet gave significantly higher leaf area index, plant height and leaf number per plant than that grown in 12°C (Caser, 2015).

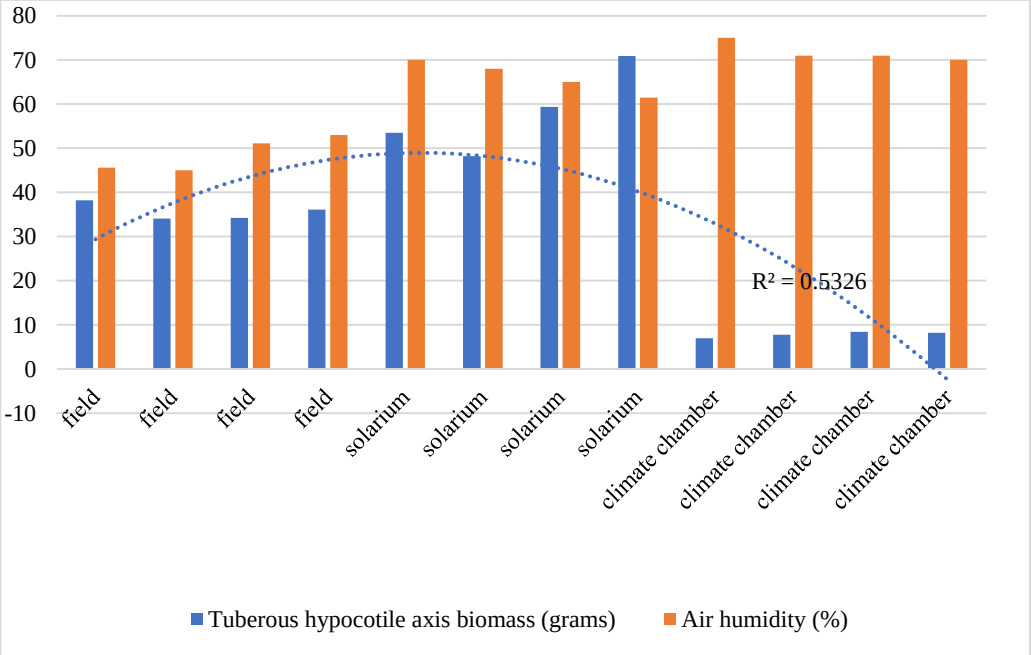



The correlation coefficient: -0.35622
The significance of the correlation coefficient: -1.20553
t: -1.81246
Figure 7: Correlations between air humidity and total plant biomass

The coefficient of determination obtained in figure 7 of 0.532 show a dependence of the total biomass of the plant on the ambient humidity in all three cultivation systems. A value of 65%-70% of air humidity can lead to obtaining a higher total biomass of radish plants. The increase in air humidity above the value of 75% in the conditions of the climatic chamber, however, led to lower values of the total biomass of the plants. In the climate chamber, the total biomass recorded the lowest values. Under the influence of air humidity, the total biomass recorded the highest values in the crops in the solarium followed by those in the field.

There is a moderate bond between the two parameters considered (air humidity and biomass of the tuberous hypocotyl axis), according to the correlation coefficient obtained in figure 8. The value of the coefficient of determination shows that in 53% of cases the variation of the tuberous hypocotyl axis biomass is determined by the air humidity variation. In the cultivation conditions provided by the climatic chamber, the biomass of

the tuberous hypocotyl axis recorded much lower values compared to the other two cultivation systems. High values of air humidity (over 70%) negatively influence the accumulation of biomass in the tuberous hypocotyl axis. The highest values of the biomass of the axis of the tuberous hypocotyl were recorded in the solarium and in the field culture under the influence of air humidity.

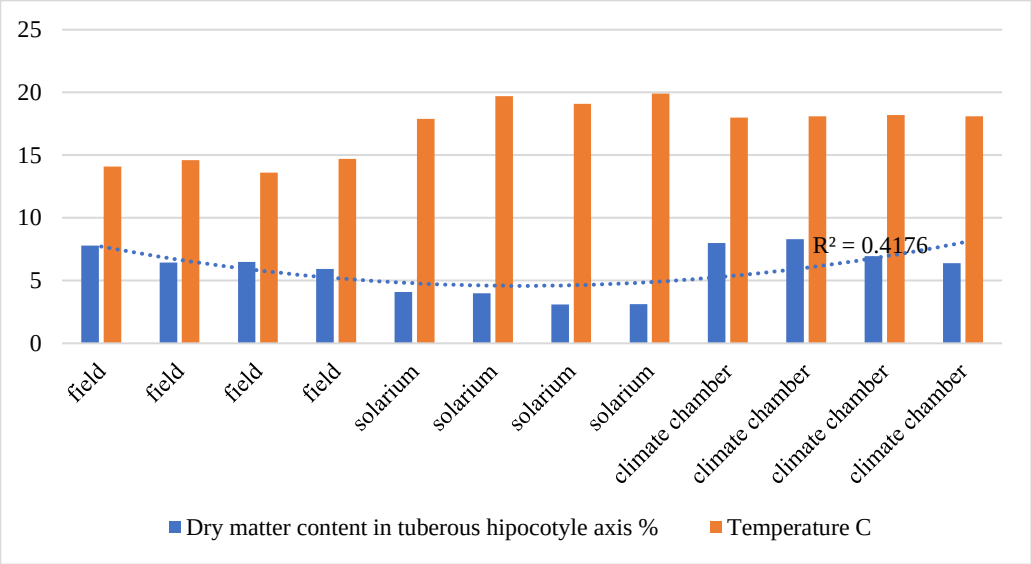



The correlation coefficient: -0.32916
The significance of the correlation coefficient: -1.10234
t: -1.81246
Figure 8: Correlations between air humidity and tuberous hypocotyl axis biomass

Figures 9 and 10 show the relations between temperature and the average dry matter content in the hypocotyl axis and in the leaves. The coefficient of determination obtained (0.3694 and 0.4176) shows a moderate influence of the temperature on the accumulation of dry matter in radish plants, regardless of the cultivation system. High values of the dry matter were observed in the plants grown in the climate chamber where the temperature was constant. In the case of field and solarium crops, the values of the dry matter content varied depending on the temperature variation. The lowest values of the dry matter were observed in the radishes grown in the solarium. High temperature values (over $19.9^0$C) negatively influenced the accumulation of dry matter, both in the tuberous hypocotyl axis and in the leaves. Dry matter accumulation in radish leaves is dependent on photosynthesis and assimilate partitioning which are highly influenced by ambient temperatures.

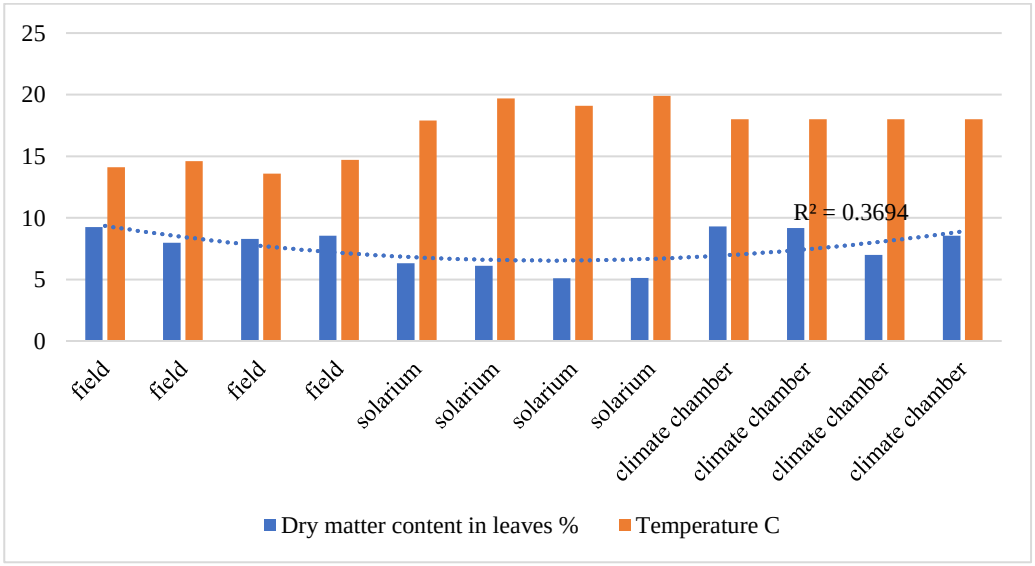
Anonymous and Kasperbauer (2002) concluded that at warmer temperatures, the effect of light intensity on carrot plants was more significant than at cooler temperatures. Photosynthesis in many plants was found to increase as temperature increases. Thus, the analysis demonstrates the relationship between the characteristics of the leaf and the rosette with the signs of productivity. The length of the root and index of the root is not

related to the diameter. The dry matter content is associated with the duration of the vegetative phase, which implies that, with an increase in the maturation period, more dry matter accumulates in root crops (Kurina *et al.*, 2021).



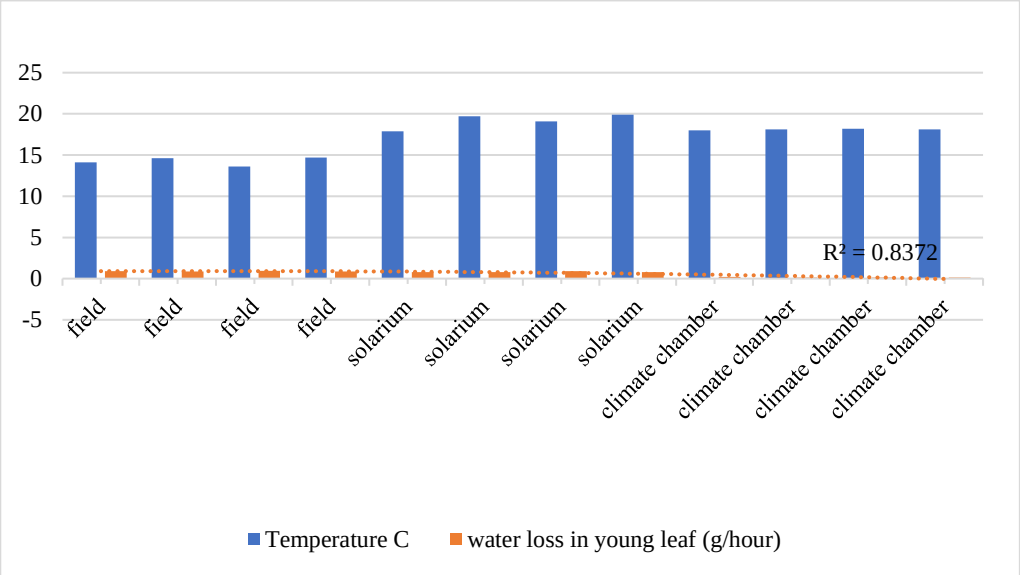

The correlation coefficient:-0.57263
The significance of the correlation coefficient:-2.208882
t: -1.81246

Figure 9: Correlations between temperature and the average dry matter content of the tuberous hypocotyl axis

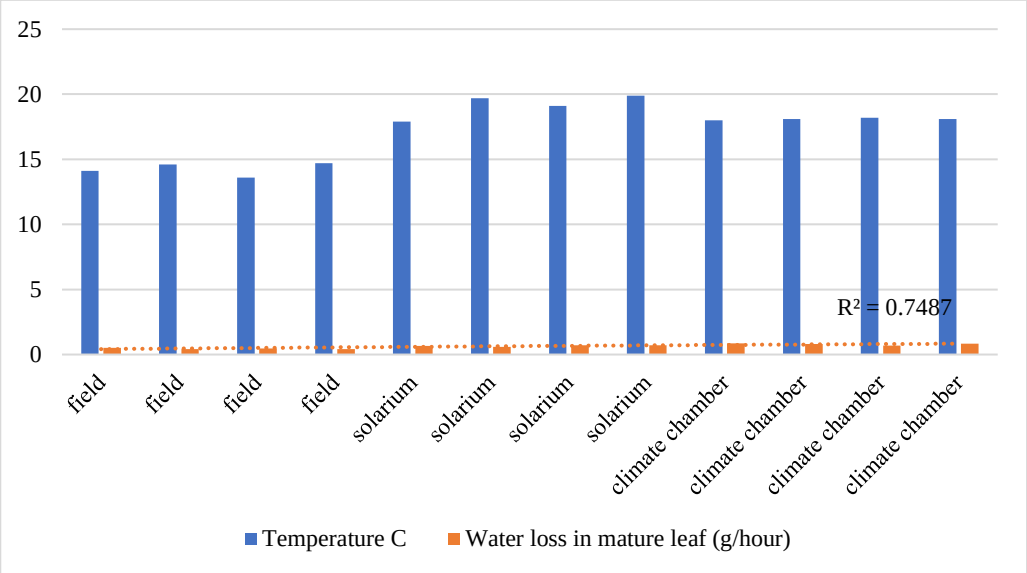



The correlation coefficient: -0.60959
The significance of the correlation coefficient: -2.43175
t:-1.81246

Figure 10: Correlations between temperature and the average dry matter content of the leaves



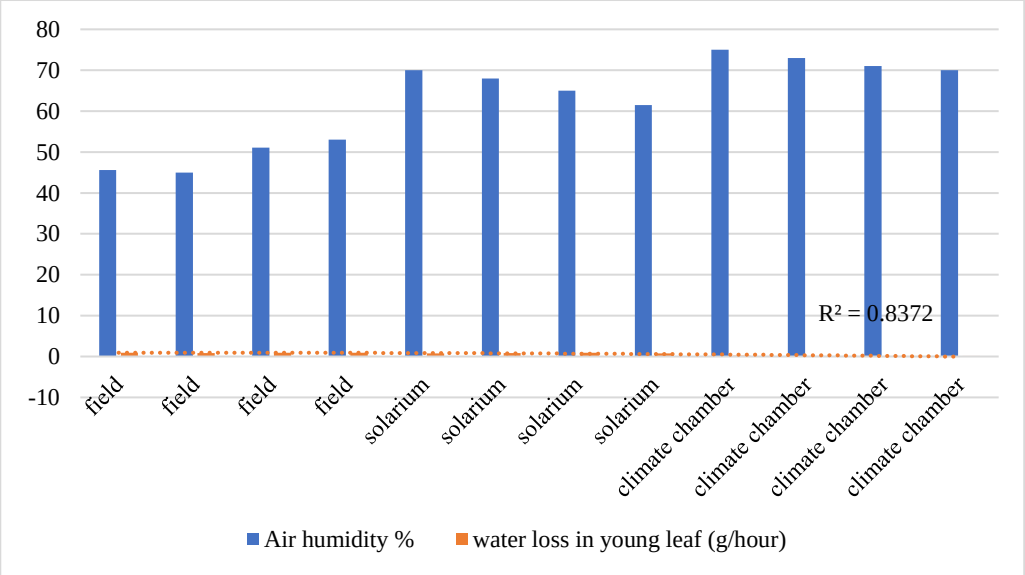

The correlation coefficient: -0.22637
The significance of the correlation coefficient: -0.73493
t: -1.81246
Figure 11: Correlations between temperature and perspiration intensity (young leaf)




The correlation coefficient: 0.459192
The significance of the correlation coefficient: 1.634619
t: -1.81246
Figure 12: Correlations between temperature and perspiration intensity (mature leaf)

Figures 11 and 12 show the relationship between temperatures and the intensity of perspiration in young and mature leaves. The change in the intensity of the perspiration process is determined by air temperatures. The higher it is, the more intense the

perspiration. According to the coefficient of determination, between 74% and 83% of the variation in the intensity of perspiration is dependent on the variation in temperatures. In this case, the correlation coefficient shows a moderate influence between the two parameters. In the case of young leaves, the intensity of perspiration was stronger in field and solarium crops and weaker in the case of plants grown in the climate chamber. The mature leaves showed a higher intensity of perspiration in the case of radishes grown in the climate chamber. In field and solarium crops, the values of water loss through transpiration were relatively close to each other in mature leaves.



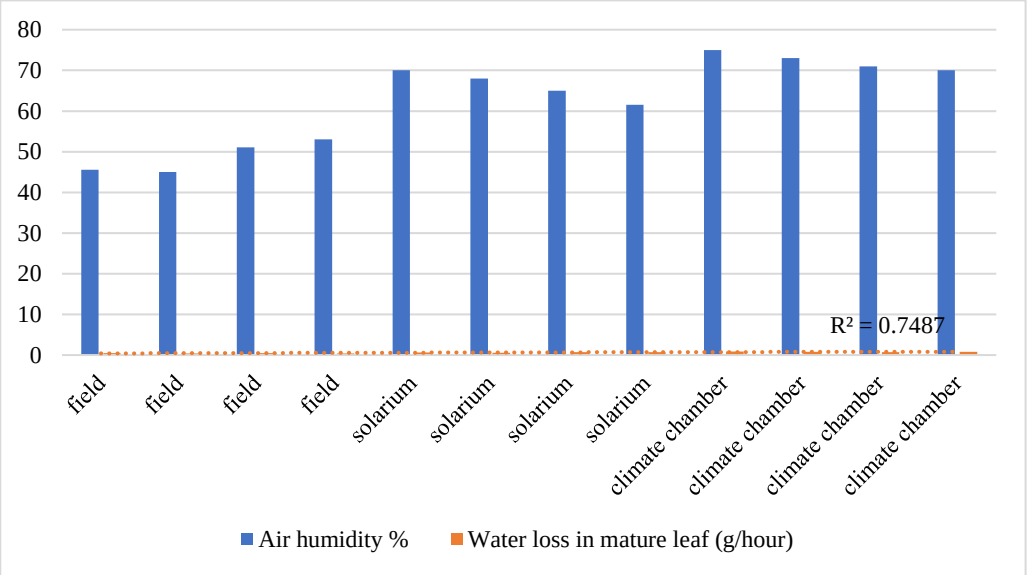

The correlation coefficient: -0.72132
The significance of the correlation coefficient: -3.29337
t: - 1.81246
Figure 13: Correlations between air humidity and perspiration intensity (young leaf)

Figures 13 and 14 show the relationship between humidity and the intensity of perspiration in young and mature leaves. Air humidity has a direct action on perspiration. The higher it is, the intensity of perspiration is reduced. According to the coefficient of determination, between 74% and 83% of the variation in the intensity of perspiration is dependent on the variation in air humidity. In this case, the correlation coefficient shows a strong bond between the two parameters. Air humidity influenced, to a greater extent, the intensity of the water loss process in young leaves compared to mature leaves.

## Conclusions

The maximum number of leaves, as well as the maximum amount of biomass and the circumference of the tuberous hypocotyl axis were achieved by the plants grown in the solarium. High moisture content of tissues was observed in plants grown in the solarium. Nevertheless, the maximum amount of dry matter was achieved by plants grown in the field. The highest firmness was recorded at the hypocotyl axis of the radishes cropped in the solarium. Young leaves of radishes grown in solarium and field lost the largest amount of water through the process of perspiration. The content in soluble dry matter

was higher in the radishes grown the field, and the highest content in total soluble carbohydrates was noticed in the radishes grown in the climate chamber, followed by the radishes grown in the solarium.




The correlation coefficient: 0.872986
The significance of the correlation coefficient: 5.659981
t: - 1.81246

Figure 14: Correlations between air humidity and perspiration intensity (mature leaf)

Glucose and vitamin C content was significantly higher in the hypocotyl axis of radishes grown in the climate chamber. The influence of temperature had a very strong impact in the development of the tuberous hypocotyl axis biomass, the total biomass, the number of leaves, the dry matter content and the intensity of perspiration. Humidity strongly influenced the total biomass of the plants and the biomass of the tuberous hypocotyl axis. Moreover, humidity strongly influenced the intensity of the perspiration. Biometric, physiological, and biochemical parameters varied from one culture system to another. The radishes obtained in the solarium were close to the requirements of the consumers. They show a higher firmness, a more intense color of the epidermis of the hypocotyl axis and they are preferred by the consumers.

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## Authors' Declarations and Essential Ethical Compliances

*Authors' Contributions (in accordance with ICMJE criteria for authorship)*
This article is 100% contributed by the sole author. She conceived and designed the research or analysis, collected the data, contributed to data analysis and interpretation, wrote the article, performed critical revision of the article, edited the article, and supervised and administered the field work.

*Funding*
No financial support was received for the research and writing of this article.

*Research involving human bodies or organs or tissues (Helsinki Declaration)*
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

*Research involving animals (ARRIVE Checklist)*
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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*(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)*
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